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Virtual Prototype Radio Frequency Weapon Project Visualization: A Case Study

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ABSTRACT

At the 1997 DoD HPC User Group meeting, the Virtual Prototype Radio Frequency Weapon Project was described as "…an ambitious effort to use newly-developed plasma, particle beam, and electromagnetic codes to design useful high power radio frequency (RF) weapons components via parallel computation." (Ref. 1) This paper will describe the methods used by the Scientific Visualization Center at the CEWES MSRC to work with these remote users to visualize the ICEPIC portion of the simulation. Some of the useful methods developed for this effort include a preprocessor that resamples the electron field to produce a compact file for viewing; a combination of custom and commercial code for the visualization; and a dual visualization approach where components are developed at CEWES MSRC and then sent to the customer for reuse on their workstation.

1.0 PROJECT BACKGROUND

The Scientific Visualization Center (SVC) at the Army Corps of Engineers Waterways Experiment Station (CEWES) Major Shared Resource Center (MSRC) began discussions in the fall of 1997 with Dr. Robert E. Peterkin, Jr.'s team at the US Air Force Research Laboratory at Kirtland AFB in Albuquerque, NM. Their team had been awarded an HPC Challenge project that included cycles on the CEWES MSRC IBM SP (180,000 hours) to continue the development of their virtual prototype of a radio frequency weapon.

Three simulations are being used to develop a device that generates intense radio waves. First, the MACH3 simulation is used to optimize the voltage source which needs to produce a pulse that, within a few nanoseconds, reaches voltages on the order of half a million volts. The design consists of an explosive core; a current-carrying inner wire coil that is driven outwards by the explosive; and an outer wire coil into which the voltage source is induced. Visualization tools to support MACH3 are just now being developed at CEWES MSRC and so are not included in this report. Second, the PARANA simulation is a frequency-dependent model of the antenna that collects and directs the generated RF energy. It is a pseudo-parallel code for which there are currently sufficient visual tools. Third, the ICEPIC simulation is used to design the main body of the device that converts the voltage source to RF energy. It is a particle-in-cell, parallel code that models the generation of relativistic electrons and both the applied and generated electromagnetic fields. Up to five geometrical designs will be studied of which the Magnetically Insulated Line Oscillator

(MILO) and Relativistic Klystron Oscillator (RKO) designs have received the greatest focus to date (Ref. 2, 3)

At the time the CEWES MSRC SVC became involved, the researchers had developed some two-dimensional visualization tools (using, for example, TEKPLOT) but felt that they could use assistance in the development of more powerful three-dimensional visual tools.

2.0 IN-THE-LOOP VISUALIZATION: A MODEL PROJECT

The usefulness and quality of a visualization product depends as much on the management of the project as on the hardware and software. The following describes some of the challenges facing most projects as well as the approach used at CEWES MSRC to successfully overcome these challenges for the RF Weapon project.

2.1 Typical Visualization Projects

The principle investigator using an HPC deals with a great many technical issues including the algorithms, parallelization and data storage requirements. It is easy to understand why there seems to be little time to worry about the end of the project, when high-level visualization is typically first considered. The irony of this view is that visual analysis tools can provide a benefit – perhaps their greatest benefit – long before a project is completed. The best way, in many cases, to assess the scientific and computational validity of an application during the develop/test/revise loop is through flexible visual tools. As a project begins to produce reportable results, scientific visualization begins to shift to its second role as a method for communication to the researcher's peers and sponsors. Many excellent visualization packages are available, but even the best are useless unless they can read the HPC data. When visualization issues are postponed to the end of the project, the visualization team may end up spending more time on data management and conversion than on the visual work itself.

In summary, by thinking of visualization as external to HPC research rather than an integral part, the opportunity to augment all phases of the project can be lost, less time is available to polish the finished product because of time spent to perform data conversion, and all parties are left with many areas of frustration.

2.2 Radio Frequency Weapon (RFW) Project

The single most effective step taken to integrate visualization into the RFW project was the involvement of the CEWES MSRC SVC within the first month of the beginning of the project year. Several weeks were then spent trading email messages and hand-drawn sketches of the desired visual products. This activity had several benefits. First, a common ground was found between what was desired and what was practical. Second, the visual products for the entire year were planned from the start which made it possible to select technical approaches that would be useable for all. And third, clear priorities were set so that the SVC produced the visual products in the order most beneficial to the customer.

An additional benefit is that presentation-quality results could be produced at any stage of the project using the same tools developed for everyday use. Although the development of the RFW simulation is not complete, a rich selection of wall posters and videos have been produced.

3.0 PROJECT MANAGEMENT APPROACH

Successful visualization results sit at the top of a pyramid of scientific and management successes. The following summarizes the approach used at CEWES MSRC to help guarantee these successes.

3.1 CEWES Challenge Support Teams

Each Challenge Project has a support team with members drawn from the Computational Migration Group (CMG), Applications Group, PET and SVC. A single CEWES MSRC point of contact is selected to handle most issues and to coordinate the delivery of productive computing cycles with other CEWES MSRC projects. The visualization team is involved from project inception and can draw upon an in-depth pool of talent that includes tool developers, animators and video specialists.

3.2 Establishing a Working Relationship

Since the RFW project personnel would be working with the CEWES MSRC SVC team throughout the project year it was vital that a good working relationship be established as early as possible. Several steps were taken to achieve this. First, as noted earlier, a series of email messages and sketches were traded to define the goals. Second, the SVC requested and received copies of the project proposal and other technical papers to better understand the scientific and developmental challenges faced by the RFW personnel. Third, to help reduce the effects of distance, the entire Challenge Support Team visited Kirtland AFB where they received an intense introduction to the project's history, a review of previous videos and presentations, and some good Mexican food. Finally a mechanism was established for SVC access to the HPC data and the project team's access to the latest version of the SVC visual tools.

4.0 PROJECT TECHNICAL APPROACH

The RFW project chose to use visualization as a post-run analysis tool. The following paragraphs describe the basic technical problems encountered and the solutions provided by the CEWES MSRC team.

4.1 Typical Remote User Problems

Many HPC applications produce extremely large data sets of up to a terabyte that can take hours to weeks to transmit to a remote user's site. Even the availability of high-speed networks like the DREN cannot completely solve the problem if the user's site is using a slower local network. As an alternative, some users have suggested that the SVC process the data and then transmit the resulting visualization files to the remote site. While this can be an effective solution in some situations, it has several drawbacks for others. The SVC systems typically do not have more than a few tens of gigabytes available, at best; and the resulting image or movie files, for a thorough study of the data set, can be as large as the original data set.

The SVC also faces a challenge in the selection of the visualization software package best suited for either a local or remote user. Commercial off-the-shelf (COTS) packages are often the easiest approach as they can offer a rich set of sophisticated features. However, they can also be difficult to master and are seldom compatible with the HPC data set formats.

4.2 Solution for the RFW Project

The first part of the CEWES MSRC solution was the creation of the RFW Particle Compression (RFWPC) program. When run on the same HPC used for ICEPIC (the IBM SP), a data set of, for example, 500 files comprising 1.2 GB can be reduced to a single file of 106 MB (about 11:1). This program works by dividing the region of the weapon where charged particles are generated into a uniform grid of visualization cells. Then, at each time step, a list of cells containing data is calculated and written. The user can select the grid size (typically 256 cubed) and other processing options. Note that this grid does not directly correspond to the one used in the particle-in-cell algorithm.

The second part of the CEWES MSRC solution was the selection of the Advanced Visualization System (AVS) as the main visual package for this project. The RFW project had already selected AVS and an SGI workstation a year earlier but had not yet been able to put AVS to good use. AVS had already been used extensively at CEWES MSRC, also on SGI systems, so that any AVS-based tool developed at the CEWES MSRC SVC could be easily passed on to Kirtland. Representatives of the ASC MSRC provided an introduction to AVS at Kirtland. CEWES MSRC personnel developed and delivered several custom AVS-based components including a module for reading the RFWPC files and for reading drawings in the Wavefront OBJ format (for showing the device geometry). The CEWES MSRC SVC also provided a sample AVS network that combined all of these features into a complete visualization solution.

The complexity that a user of AVS encounters is illustrated in Figure 1. The icons represent pieces of the AVS user interface and the custom RFWPC file reader.

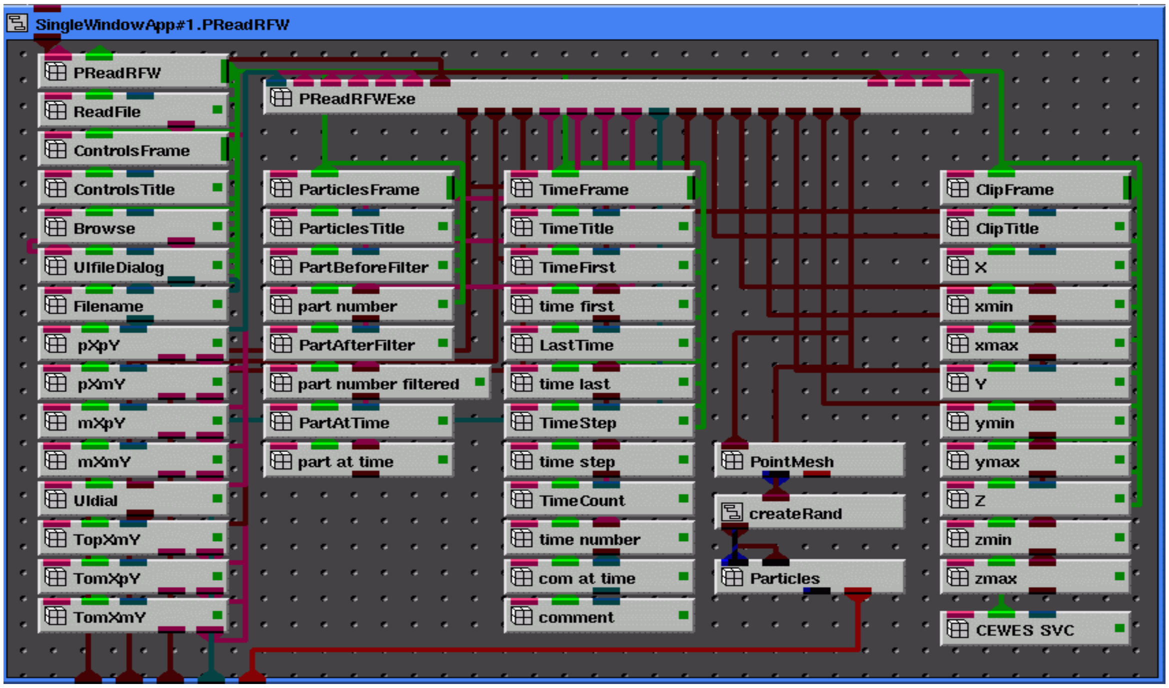

Figure 1. Custom RF Weapon Data Reader including the user interface components

Fortunately, all this detail can be hidden by collapsing all of the components shown in Figure 1 into the single macro titled "PReadRFW" in Figure 2. The user would add to the network in Figure 2 to extend the basic visualization.

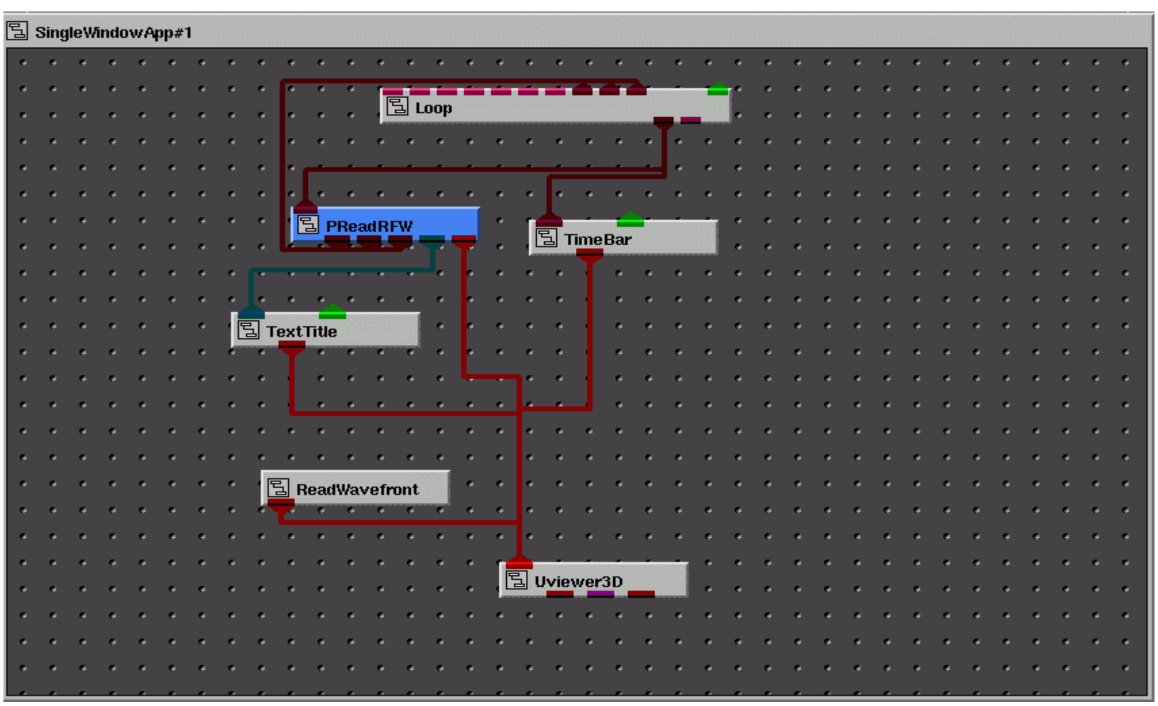

Figure 2. Data reader from Figure 1 has been collapsed to an icon and combined with other standard AVS modules

Finally, Figure 3 shows the complete user interface for the PReadRFW macro that requires only easy-to-use point-and-click operations. The visualization produced is shown in Figure 4 (an animated version of this image has also been videotaped).

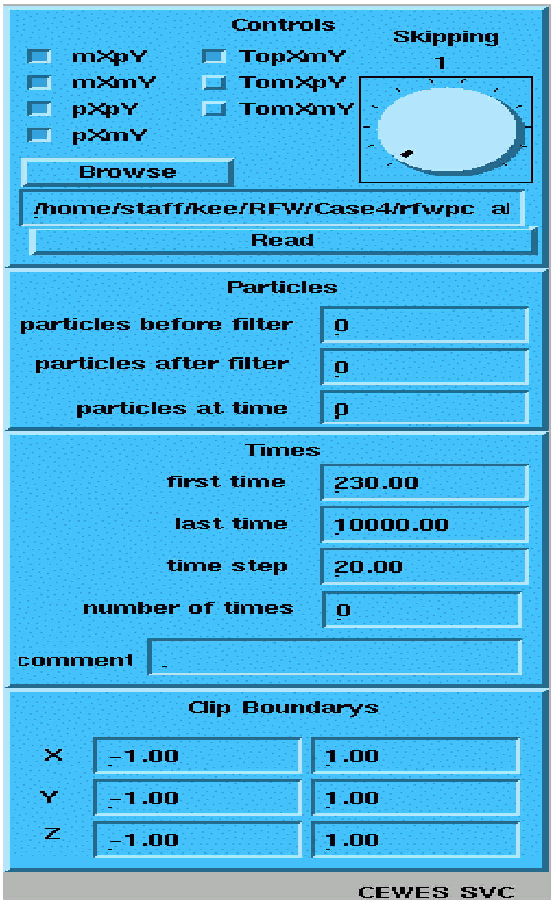

Figure 3. The resulting user interface hides the details and is easily understood by the customer

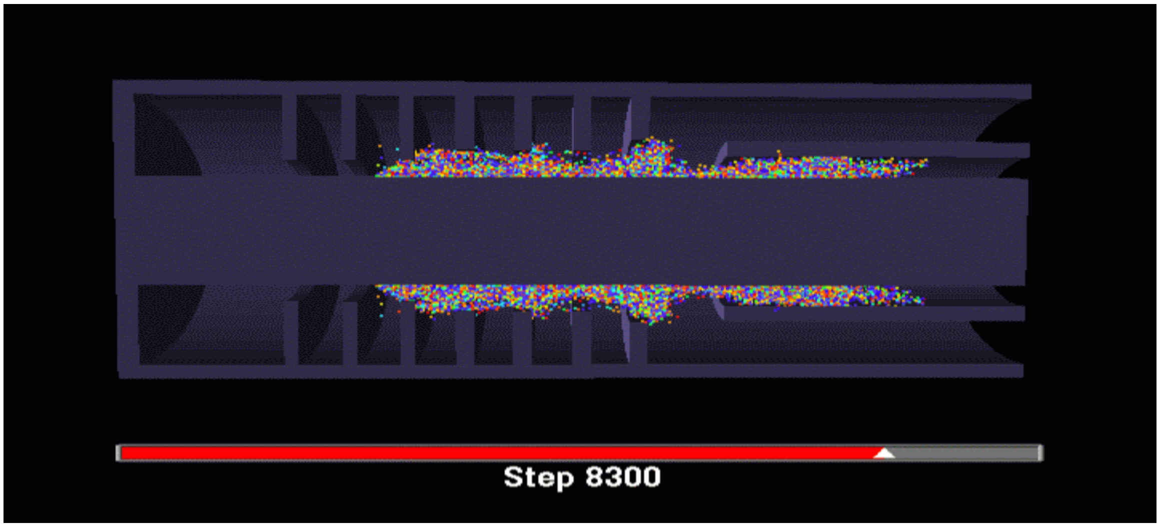

Figure 4. The user can run the visualization in time and rotate the view in 3D

In spite of the custom nature of the work done for this project, we have found that almost every piece can be used or adapted to other projects underway at the CEWES MSRC SVC.

5.0 SUCCESSES THUS FAR

As with any significant visualization effort taken on by the CEWES MSRC SVC team, the first major goal is to deliver quality visual products that can be used by researchers during all phases of the develop/test/revise loop. Due to the conscientious efforts of both the RF Weapon scientists and the CEWES MSRC SVC team, this goal has certainly been met. However, one of the other goals of the CEWES MSRC SVC is to provide technology transfer to the user. In addition to delivering quality visual representations of the simulation data, CEWES MSRC SVC staff members have also facilitated this technology transfer through the basic features and custom enhancements created for AVS. The customer can now use AVS and CEWES MSRC-developed enhancements to view new data sets on their workstations. Without CEWES MSRC SVC involvement, RF Weapon researchers can use these tools at their site to visualize data sets as they are produced. These tools have also been used to produce videos for project presentations and to produce PSCologram and light box transparencies to help explain the concept of the project.

6.0 FUTURE ENHANCEMENTS

The next version of the RF visualization tools is scheduled for delivery in August 1998. The particle compression program will be enhanced to use a greater number of visualization cells and generate the following information about each cell:

- The number of particles in visualization cells
- The sum of particle momentum in a visualization cell
- The sum of the particle charge in the visualization cell

In addition, an option will be added to save the visualization cell array so that additional visualization methods can be used. These methods will include isosurfaces (of particle count, momentum or charge) and cut planes.

We also have been working with the developers of the MACH3 simulation to find an approach that will support three-dimensional displays of their data without requiring major changes to the simulation. At this point, we believe the best approach is to develop a custom AVS input module that can read the existing MACH3 output intended for TEKPLOT. This work is scheduled for late summer.

7.0 ACKNOWLEDGEMENTS

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8.0 REFERENCES

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